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GEOLOGY OF MONADNOCK MOUNTAIN, NEW HAMPSHIRE.[1]

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MONADNOCK, situated in southern New Hampshire, is of special interest to geologists because it was selected by Professor Davis as a type of the isolated, residuary peaks that may be found rising above a base-leveled land surface. This mountain rises 3,166[2] feet above mean sea-level and about 2,000 feet above the surrounding peneplain, the plateau of southern New England. At the first glance the mountain may appear, from its representation on the *Topographic Map*, as a regular, single peak; but, on closer study of the map and of the mountain from different sides, it is seen to consist of two well-defined parts. There is a northeast-southwest ridge, about six miles in length, extending from the center of Dublin to Gap Mountain. This constitutes the eastern part of Monadnock. This ridge rises by a succession of steps from an elevation of 1,500 feet at its northern extremity to 2,800 or 2,900 at its culmination east of the summit of the mountain, and then descends by a like succession of steps to its southern extremity.

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[1] Monadlock is considered in the *Geology of New Hampshire*, Vol. II, pp. 24, 503, 639. This area, with a section through the mountain, is represented on the fourth sheet of the geological map in the atlas accompanying the same.

[2] From he *Topographic Map* of the U. S. Geological Survey.

The eastern slope of this ridge above the foothills is quite steep, even precipitous. The western part of the mountain, which includes the summit, rising 300–400 feet above the eastern ridge, consists of a single peak set, as it were, in the central part of the western slope of the ridge. The northwest slope of this peak is gentle; the west and southwest slopes are much steeper; while the northeast slope meets the northern half of the western slope of the ridge forming the valley of Mountain Brook. These divisions and their slopes are closely related to the underlying rock structure, and indicate that erosion is controlled or guided by this structure.

The rock of this mountain is a banded mica schist, the banding being generally parallel to the present structure. The schist presents three marked variations. In the top of the mountain and in the upper part of the eastern ridge it is a gray, massive, garnetiferous, biotite, sericite schist, in which the biotite is specially noticeable because of its arrangement in bright, isolated scales, one-sixteenth of an inch in diameter, set in a fine, light gray groundmass.[1] In addition, andalusite crystals, or what were once andalusite crystals, occur in this schist, sometimes very abundantly, lying parallel to the present structure of the rock. The accompanying picture (Fig. 2) shows how abundantly these may occur in the schist. They are frequently five or six inches long by half an inch, or more, through Owing to the unequal weathering, these prisms frequently appear in relief on the surface of the ledges. In the southern half of the ridge, and also in the western peak of the mountain, these prisms are now largely, if not entirely, made up of fine, glassy, colorless or white fibers of fibrolite. In the northern part of the eastern ridge, and in other parts of the mountain in limited areas, the andalusite crystals have changed to masses of white, pearly sericite scales. In the weathering these sericite masses are removed more rapidly than is the inclosing rock, producing long narrow cavities on weathered surfaces. Where the end of the sericite mass is exposed, the weathering is more rapid in the center, producing a cavity bordered by a sericite shell.

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[1] In the *Geology of New Hampshire* this schist is called the Kearsarge andalusite schist.

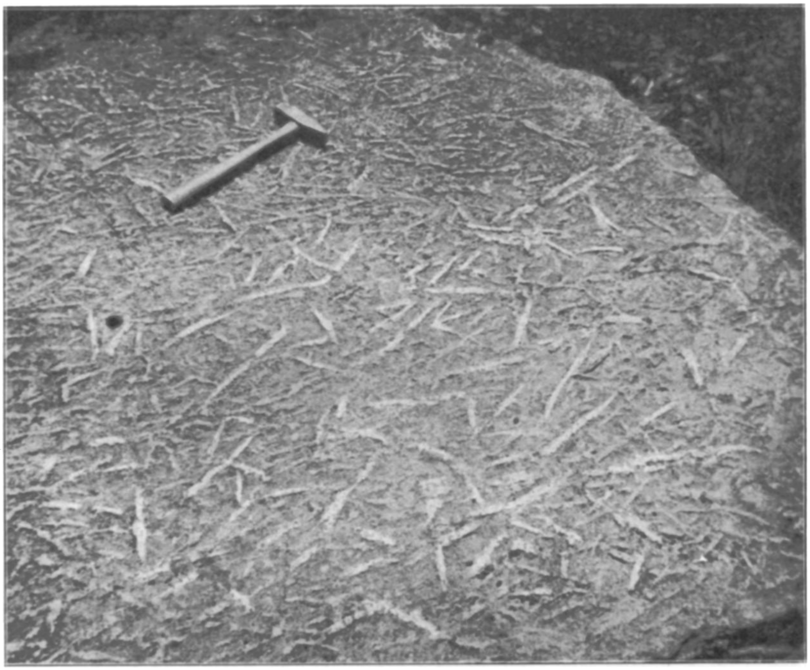

FIG. 2.—Surface of Andalusite mica schist.

In the southern part of the mountain the schist becomes, by alternating areas, a fibrolite schist, the fibrolite being original; but even within this fibrolitic area appear small areas where the rock originally contained andalusites. It is impossible to draw a line correctly separating this schist into two parts, so intimately associated are the original fibrolite and pseudomorphs after andalusite. As the schist becomes fibrolitic, it is distinctly and quite thinly laminated. It also contains garnets and tourmaline and, rarely, graphite in fine scales.

In the middle of the northeast slope this schist is destitute of fibrolite and pseudomorphs of andalusite; it is characterized by a dark green mica of soapy feel, and a very fine, white sericite. The latter is in fibers as fine as the fibers of fibrolite, and occurs in the schist just as fibrolite occurs in other parts of this schist. The sericite is evidently fibrolite changed into sericite, as is proved by the finding of a mass of fibrolite partly so changed. In the general sericitization to which this schist has been subjected the fibrolite, in places, has been changed as well as the other minerals. This sericitization indicates the permeation of this schist by potash solutions. These variants are considered as one schist, and are so colored on the geological map.

The second phase of the mica schist, found in the mountain and the surrounding area, may be seen between the 1,600 and 1,700-foot levels on either side of the road on the southern slope. It is a gray, thinly laminated, finely granular, quartzose mica schist, containing, in addition to the granular, glassy quartz, a little fine, brown mica and fine, light green hornblende. This schist is cut by lamination planes and joints into thin, rectangular slabs. In position it is conformable with the fibrolite-andalusite schist above. The boundary between the two is a zone of alternation. This indicates either an alternation of sediments or an interfolding along the border. I judge that the former is the case here, because in other parts of this area the quartzose schist blends into, and alternates with, the third phase of the mica schist. In only this small area on the southern slope is there enough of this quartzose schist by itself to be represented as a distinct area on the map.

The third phase of the mica schist occurs below the second, on the southern slope, and is the first rock met in going up the mountain road. This is a very rusty, thinly laminated, frequently fissile, muscovite, biotite schist which often becomes so quartzose as to be a micaceous quartzite. The extreme rustiness is due to iron pyrites. Little scales of graphite are characteristic of this phase of schist, and are sometimes abundant enough to give a gray color to the unrusted rock. Fibrolite was not observed with the graphite, though in the more micaceous, or first phase of the schist, fibrolite and graphite may sometimes be seen together. This rusty phase occurs over quite an area in the southeastern part of the region represented in our map, and also in the northwestern part, and on the southeastern slope of Gap Mountain. In all of these areas there is no well-defined border between the first or fibrolitic phase and the third or rusty, graphitic phase; there is a blending of one into the other, and they are equivalents. The second phase also is only a variant of the third.

Included in the area of the accompanying geological map, though not a part of the mountain, are granite masses which are closely connected with the rock structure of the mountain, and with other phenomena revealed in this study. Where this granite adjoins rusty schist, it has a dark gray color, is more or less rusty on weathered surfaces, and is of medium fine, granular texture.

The quartz and the feldspar form an intimate granular mixture, in which the biotite is quite uniformly distributed in fine scales. Muscovite occurs in varying quantity, but is not characteristic of the granite, as biotite is. Fine magnetite and little, brown, wedge-shaped crystals of titanite occur in this granite along with some small particles of secondary epidote. Along the immediate border the granite sometimes contains black tourmaline. Tourmaline is, however, more frequently seen in the schist.

Away from the schist the granite is lighter in color, more muscovitic and less biotitic, contains less of the other minerals—is, in fact, more nearly a simple, medium fine, crystalline mixture of feldspar, quartz and mica. In mapping the granite this variation is a good index of the nearness or remoteness of the schist border.

In places the granite, in the southern part of this area, is porphyritic, the feldspar phenocrysts sometimes measuring an inch by one quarter, and showing the Carlsbad twins. The feldspar of the groundmass is partly triclinic. The granite of the northeastern part of the area of our map is prevailingly porphyritic, and closely resembles the granite already described, except that the phenocrysts are frequently larger and sometimes show a granulated border. The granite of these areas is frequently foliated near the schist border, and parallelly to the lamination of the schist.

On looking at the map, it is seen that the granite in the southern part of this area occurs in lobes, two of which are connected, while that in the northeastern part is in the form of a long tongue extending far into the schist, though not visibly reaching the southern granite area. These are probably parts of an extensive batholite which, possibly, extends even under the mountain. This granite incloses fragments, both large and small, of the neighboring schists. Among these may be recognized some of the light gray, quartzose mica schist thoroughly brecciated, and some of the fibrolite and andalusite schists. In the last the andalusite crystals have been generally, if not always, changed as has been described before. Inclosed in the granite may be seen prismatic masses of sericite entirely separate from, though in the vicinity of, the schist, which probably represent andalusite crystals which were dissolved in the magma, and afterwards crystallized out and sericitized.

It is difficult to decide, in some parts of this area, where to draw the boundary between granite and schist, because there is frequently a zone of alternating bands extending in the direction of the strike. Such an area is represented in the extreme western part of the geological map, and also in cross-section. The meaning of such an area is that the surface of contact between schist and granite batholite was a ragged surface—the granite having penetrated the schist at intervals, and pushed apart the vertical laminæ. The erosion has brought the land surface down so as to make a section through this alternation. If the land surface had been lowered somewhat less, the rock at the surface would have been schist; whereas if the land surface had been lowered somewhat more, the rock would have been then all granite. As it is, the extension of the batholite is but a short distance below the surface.

In this granite are many pegmatite veins, varying from an inch to several feet in thickness, and frequently the pegmatite appears in the schists. Though there is a variation in the direction of these veins, the prevailing one is northerly in the southern granite lobes. This pegmatite material shows all grades of variation from the well-defined, coarse pegmatite to pure vein quartz; and all the variations evidently had a common origin.[1]

From what has been written, it is evident that schist and granite were modified by mutual contact. The extensive sericitization of one and the darkening of the other by the increase of biotite are the most noticeable effects. From these contact phenomena and from the schist inclusions in the granite it is evident that the granite is intrusive and younger than the schist.

In rocks so thoroughly recrystallized as are the schists of our study no fossils can be expected, but the graphite found in both the rusty graphitic schist and also, though rarely, in the fibrolitic schist may point back to organic remains.[2] To one acquainted with the rocks in the plateau of central Massachusetts, from Worcester to the Connecticut Valley, it is evident that these schists in and around Monadnock are but a continuation of the Massachusetts rocks, though there may be a few square miles of area between the two not yet mapped; and the conclusions that have been reached from the study of the latter are applicable to the former. After many years of study, Professor Emerson and the writer have concluded that the schists of this plateau in Massachusetts are more highly metamorphosed phases of the Carboniferous phyllite and quartzite found at Worcester.[3] If this conclusion is correct, then these schists of Monadnock are Carboniferous, and the intruded granite is post-Carboniferous.

Another fact demanding careful study is the attitude of the schist in this mountain. That the structure is not as simple as it might be is indicated by the statement on p. 639, Vol. II, of the *Geology of New Hampshire*: "In structure it (Monadnock), seems to be a double synclinal. Again, on p. 24, it is stated: "Mt. Monadnock seems to be an isolated, contorted synclinal of andalusite mica schist." The strike of the schist in the area east of the mountain, in the eastern slope, and in the northeast half of the ridge of the mountain, is between north and northeast, with a dip to the west and northwest. In the southern half of the ridge, as far north as an east-west line passing through the more southerly of the two houses on the mountain road, the strike is from north to almost east, with the dip to the northwest. In the top and in the northwestern part of the mountain the strike is to the northwest, with a dip to the northeast. In the extreme western part of the area here included, the strike is east and west north of the granite lobe with the dip varying from vertical to 40° south; and the strike is northeast on the northwest side of the same lobe, with the dip vertical. In the central part of the mountain mass, between the northeasterly and northwesterly strikes, the strike swings from one to the other through an east-west direction, with a dip of about 45° to the north.

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[1] J. E. SPURR, "Genesis of Auriferous Quartz Veins," *Eighteenth Annual Report of the U. S. Geological Survey*, Part III, pp. 311, 313.

[2] In the *Geology of New Hampshire*, Vol. II, p. 503, a graphite mine in this schist is mentioned.

[3] *Geology of Worcester, Massachusetts*, pp. 28, 50, 137, 139, 148, 152.

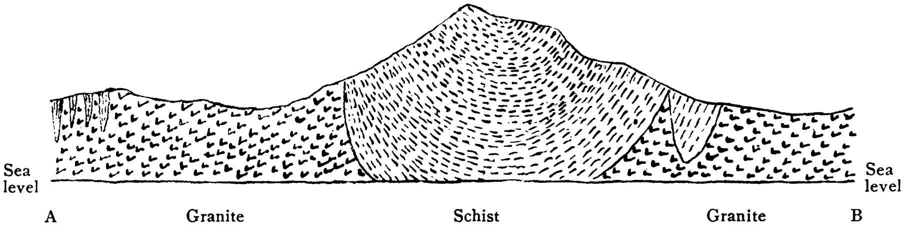

FIG. 3.—Section through Monadnock. Horizontal scale $\frac{1}{62500}$; vertical scale $\frac{2}{62500}$; made from Topographic Map of U. S. Geol. Surv.

The meaning of this variation in the dip and strike is that the schist in the northern two-thirds of this mountain mass has been folded into a synclinal having a pitch of 45° to the north; and the western limb of this synclinal is continued in an overturned anticline, with pitch to the south, around the western granite lobe. The axis of the syncline is marked, approximately by the course of Mountain Brook down the northern slope. The highest point of the mountain is not at the apex of the syncline, but is in the western limb. South of the summit this syncline may be traced along the crest of the ridge, becoming narrower, as far as the east-west line of the more southerly house on the mountain; south of this line, along the continuation of the axis of the syncline, there is a marked deviation of the strike to the east, which becomes less and less as the syncline fades out to the south.

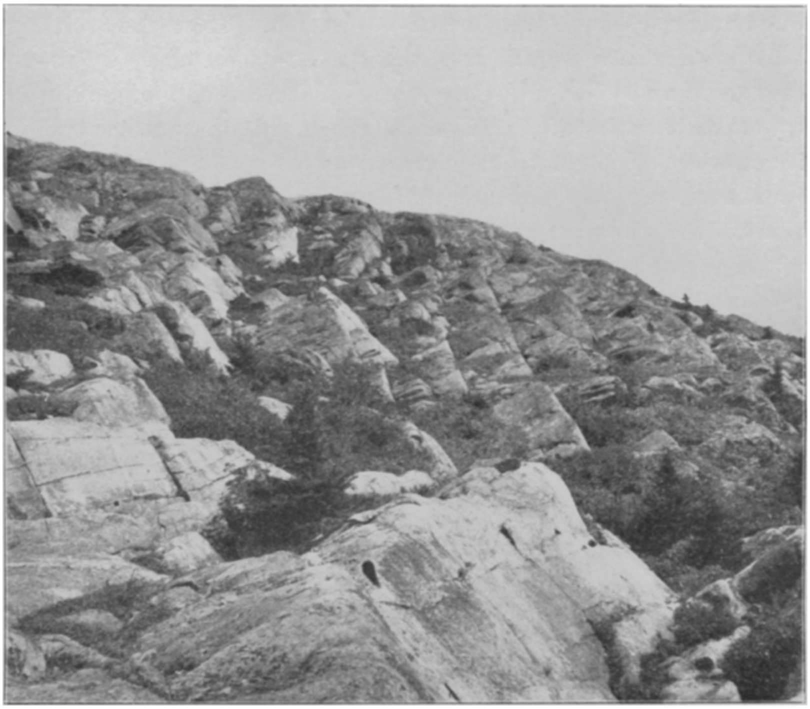

FIG. 4.—Showing the jointing in schist. West side of Monadnock, 2800-foot level, looking southeast. The joint plane slants toward the right. The dip is toward the left.

On the transparent sheet accompanying the geological map the folds in the schist are represented. The lines of strike were first plotted, and then these curves were drawn through them. In this way the anticline in the schist, as it folds around the granite lobe in the west, and the syncline in the mountain itself are clearly brought out. A glance at this sheet is sufficient to convince anyone that the folding of the schist accompanied, and was due to, the intrusion of the granite; and the force of intrusion was exerted in a northerly direction.

Closely connected with the folding is the jointing in this schist, which is very noticeable in every part of the mountain, but especially above the line of vegetation. Here the rock has been broken into large blocks, perhaps 20–30 feet long by 10–15 feet thick and wide, and these are so placed in the mountain as to make a series of steps, as is shown in the accompanying illustration (Fig. 4). This picture was taken at about the 2,900-foot level, and on the western side of the mountain. Observations of the direction and slant or dip of these joint surfaces were made up on the mountain where there was little or no vegetation, and on different sides; and they are arranged in the table below. While there are not so many observations as there well might be, they make clear certain facts or relations.

Side of Mountain and Elevation	Strike of Banding—True Strike	Dip of Banding—True Dip	Joint 1—Strike or Direction	Joint 1—Dip or Slope of Surface	Joint 2—Strike or Direction	Joint 2—Dip or Slope of Surface	Angle between Strikes of Joints 1 and 2	Angle between Dip and Dip of Joint 1
South ridge, southeast of top, 2,500 level	*70° W	45° N	80° E	......	......	......	..	..
Southwest of top, 2,850 level	*35° W	35° N E	45° W	65° S W	5° E	25° W	50	80
West of top, 2,800 level	*N & S	45° E	35° W	60° S W	E & W	Vertical	55	..
Northwest of top, 2,800 level	N & S	45° E	50° E	70° N W	80° W	75° S	50	..
North 30° west of top, 2,800 level	*20° E	40° E	32° W	60° S W	60° E	33° S E	92	..
North of top, 2,800 level	35° E	60° E	40° E	25° N W	65° W	Vertical	75	95
West side of mountain, 1,900 level	*65° W	25° N E	55° W	70° S W	60° E	40° S E	65	85
Northwest side in Marlboro trail, 2,200 level	*50° W	55° N E	55° W	35° S W	......	......	..	90
Northeast side, 2,200 level	*35° E	45° W	45° E	65° S E	......	......	..	70
Northeast side, 2,400 level	*35° E	33° W	35° E	60° S E	75° E	90°	40	87
Northeast side, 2,500 level	*35° E	38° W	35° E	90°	70° W	75° S W	75	52
Northeast side, 2,700 level	18° E	35° W	45° W	90°	85° E	80° S	50	

1. In nine marked by a *, out of the twelve, the direction of joint 1 is approximately the same as the strike of the banding; or where the banding departs by local folding from parallelism with the side of the syncline, joint 1 is parallel to the side of the syncline.

2. The angle between the strike, or direction of joint 1, and

the strike, or direction of joint 2, varies from 40° to 90°, but in five cases out of the nine is between 50° and 65°.

3. The angle between the true dip and the dip of the surface of joint 1 in five, out of seven, cases approximates to a right angle.

The meaning of observations 1 and 3 is that this schist has been broken perpendicularly to the laminæ into strips from one end of the syncline around to the other; and observation 2 shows that these strips have been broken crosswise, less regularly, into shorter pieces or blocks, the latter indicating a bending or twisting in these strips. There is, I think, no doubt but that these joints were produced by the bending of the schist into the great synclinal fold of the mountain, and this, as has been pointed out, accompanied the intrusion of the granite. The formation of the joints in this schist clearly indicates that this rock was in the zone of fracture when this intrusion and folding took place. The same is indicated by the brecciation appearing in some of the schist fragments included in the granite.

But there is another and earlier folding evident in this schist. The accompanying illustration shows a compressed, overturned anticline occurring near the top, on the west side, which is conspicuous for a distance of several hundred feet down the mountain to one ascending on that side. The part of the fold appearing in the picture is 37 feet long by 6 wide, and the apex of the fold as seen in this section points between northwest and north. This means that the fold is overturned and lies flat in the western side of the large syncline, with the apex of this small anticline pointing away from the apex of the large syncline. The formation of this small anticline, though the bending was so severe, was not accompanied by fracture, as may be seen in the illustration (Fig. 5). Other folds, though less conspicuous, may be seen of which the same is true, and the jointing of the schist cuts through these, indicating utter independence of the one of the other. Therefore, when these smaller folds were made the rock was in the zone of rock flowage. There are indicated, therefore, two periods of metamorphism — one at a greater depth when the clastic was recrystallized and in places severely folded without fracture; and the other at less depth when there was extensive sericitization, development of tourmalines, and folding with fracture accompanying the intrusion of granite.

Another point of interest in the study of Monadnock is to determine, if possible, why this rockmass has survived the profound erosion to which this region has been subjected. Dr. Gulliver,[1] speaking of this mountain, attributes its survival to the greater resistance of the rock. In making such a comparison, it is well to bear in mind that there is an element of uncertainty in that the rocks that have been removed from above an area are not always the same, at least in this region, as those that now appear at the surface, on account of the extensive intrusions of eruptives. Dr. Haye's[2] points out, in his study of the Chattanooga district,

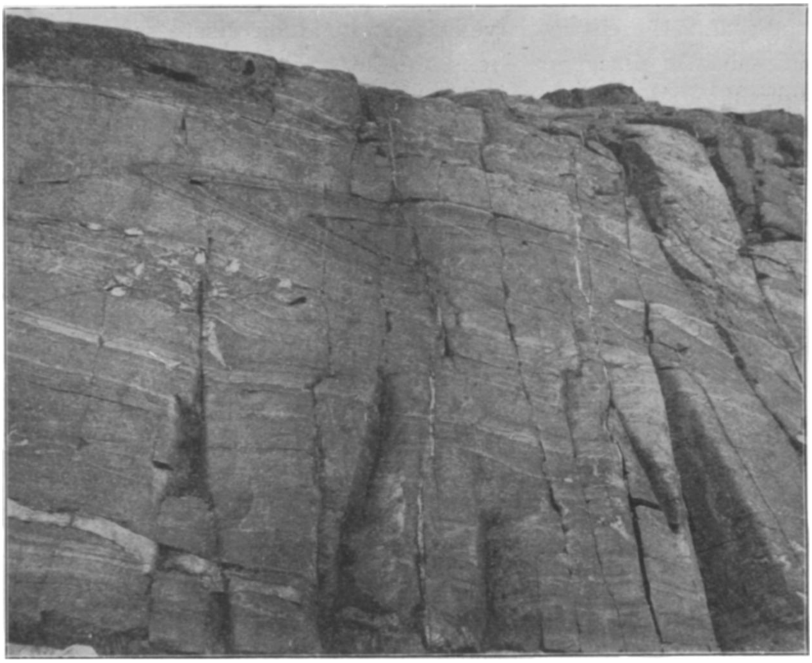

FIG. 5.—Fold in schist of Monadnock, near the top, on west side. Also shows banding in the schist.

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[1] *Bulletin of the Geological Society of America*, Vol. X, p. 19.

[2] *Nineteenth Annual Report of the U. S. Geological Survey*, Part II, p. 39.

that these residuals are the result of two factors, erodibility and location. In the case of Monadnock the second factor was probably quite as important as the first.

It must be noticed that this residuary peak does not stand alone. The one farthest south in Massachusetts, and closely related to this one, is Asnebumskit, in the town of Paxton, rising about 400 feet above the peneplain or plateau of southern New England. It is situated about a mile east of the divide between the Connecticut and the Atlantic watersheds, and at the beginning of that of the Blackstone. In preglacial times it was, very likely, on the divide between the two main watersheds. This monadnock is made up of a rusty, fribrolite schist, not to be distinguished from that in hundreds of square miles of the surrounding plateau. Next to the north is Wachusett, with two minor points associated with it, rising nearly 1,000 feet above the plateau, and situated in the town of Princeton. This is on the divide between the Ware and Nashua Rivers. It is composed of granite and the same rusty, fibrolitic mica schist, the former making up by far the larger part. There is nothing about these rocks to indicate that they are any more resisting than are similar granites and schists in the surrounding plateau. Watatic, situated in the town of Ashburnham and rising about 700 feet above the plateau, is another monadnock situated on this divide. With the rocks of this mountain I am unacquainted. Then, crossing the state line into New Hampshire, we find Monadnock also on the same divide. There are more, though smaller, residuary peaks east and west of this; and to the north still others, even rivaling Monadnock. This is just what might be expected, even in a region made up of rocks of uniform resistance—incomplete peneplanation up toward the sources of the main streams, while it is almost complete farther to the south towards the mouths of these streams. My conclusion from the study of the rocks is that these monadnocks, situated along on the divide from central Massachusetts into southern New Hampshire, owe their survival to their position rather than to the rocks of which they are composed; for in a region made up of rocks of uniform resistance and subjected to peneplanation there would be some points up near the sources of the main streams which would be the last to be brought low.[1]

SUMMARY.

1. This mountain is made out of a syncline in andalusite-fibrolite schist, probably of Carboniferous age. The syncline was produced by the intrusion of granite, which modified the schist already metamorphosed.

2. The schist contains andalusites changed to fibrolite and sericite, also fibrolite changed to sericite.

3. The jointing of the schist was produced by the folding; therefore the intrusion of the granite, which produced the folding, took place when the schist was in the zone of fracture.

4. There is an older folding evident, which must have been produced when the schist was in the zone of flowage.

5. This mountain and the other monadnocks to the south on the Atlantic-Connecticut River divide, probably owe their survival to their position, rather than to the greater resistance of the rocks composing them.

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WORCESTER, MASS.

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[1] Mount Grace, in Warwick, Mass., rising about 500 feet above this plateau, and situated about six miles from the Connecticut, far to the west of the divide, owes its survival, probably, to the greater resistance of its rocks. It is made up largely, or entirely, of amphibolites, while the surrounding plateau is made up of mica schists and granite.